Investigation of a Coastally Trapped Disturbance

William T. Thompson
Naval Research Laboratory
Monterey, California 93943
thompson@nrlmry.navy.mil

Stephen D. Burk and John Lewis

***Abstract* - The relatively shallow marine boundary layer adjacent to steep coastal topography along the California Coast give rise to a number of mesoscale phenomena, including coastally trapped disturbances (CTD's), expansion fans, land/sea breezes, low-level jets, and cyclonic eddies. CTD's occur several times each year during the period from May to early October and are easily distinguished in satellite imagery due to the distinctive narrow tongue of low clouds and fog propagating to the north along the coast. In the present study, we investigate a CTD event which occurred 15-16 June 2000. We use the Naval Research Laboratory's nonhydrostatic COAMPS™ model to simulate this event.**

1. INTRODUCTION

One of the earliest studies of coastally trapped waves was that of [2]. In this study of events along the coast of Southern Africa, the author found that many of the observed features were consistent with a nonlinear forced Kelvin Wave. Subsequent investigations have suggested that observations are consistent with coastally trapped density currents [6], [9]. However, as shown by [8], both the Kelvin wave and density current interpretations are consistent with a generalized nonlinear Kelvin wave. Their results indicated that either a solitary Kelvin wave or a shock Kelvin wave develops depending on the magnitude of the onshore component of the wind near the leading edge. More recent investigations suggest that the Kelvin wave and density current interpretations may apply at different stages of the same event.

An important characteristic of these events is the narrow tongue of fog along the coast that propagates to the north a few hours behind the wind shift from NW to SE. There have been relatively few studies of the cloud field associated with CTD's.

In the present study, we investigate a CTD event which occurred on 15-16 June 2000. On the afternoon of 15 June, fog in Monterey associated with this event caused a suspension in play at the U. S. Open golf tournament being held at this time. The event is simulated using the Naval Research Laboratory's COAMPS™[1] model.COAMPS™ is described by [3]. The model 12 h forecast for the period 1200 UTC 15 June to 0000 UTC 16 June reproduces the movement and speed of the fog along the coast north of Point Conception. In an effort to understand the evolution and extent of fog and low clouds in this event, several sensitivity studies are performed.

2. RESULTS

A. *Synoptic Setting*

The event of interest occurred over a 60 h period, from 1200 UTC 13 June to 0000 UTC 16 June 2000. The sea fog first appeared in the California Bight and progressively moved northward to Pt. Arena. A satellite image valid 2100 UTC (1400 LT) 15 June 2000 is shown in Fig 1. Transitory synoptic weather has been shown to influence the generation and longevity of sea fog [1], [4], [5]. Accordingly, we give attention to

[1] COAMPS is a trademark of the Naval Research Laboratory

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14. ABSTRACT

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the larger-scale flow that accompanied this sea fog event.

On June 12-13, a strong pressure ridge built and moved into the Pacific Northwest. Northeast winds in the 850/700 layer were in evidence over the north and central California coast. The subsidence and associated adiabatic warming led to record breaking temperatures in the central valley extending into southern California.

The satellite imagery on 14 June showed a wide swath of clear sky off the California coast - a response to the strong subsidence as shown in Fig. 2. In this figure, the instantaneous estimates of the vertical velocity have been found by determining the magnitude of the component of the horizontal wind on the 310 K isentropic surface along the gradient of height on this same surface. We have chosen the 310 K surface since it depicts the flow above the marine layer off the central California coast.

Subsidence as great as .05 m s^{-1} is indicated over northern California, trailing to .01 m s^{-1} in southern California

During the period of pronounced offshore flow in the 850/700 mb layer (13-14 June), the winds at the ocean surface are out of the north to northwest (off the northern and central California coastline). These winds, typically 7-15 m s^{-1}, are in response to the strong surface pressure gradient. This gradient dramatically weakens over the next 48 h. In the presence of this weakening surface pressure gradient, sea fog forms in the California Bight and subsequently moves northward. This can best be viewed by recourse to the buoy records (and one C-MAN station - Coastal Marine Automated Network). These records are displayed as time series at each of the stations in Fig. 3 (at the end of this paper), where winds, air temperature (T_a), dew point temperature, and SST are plotted [The C-MAN station (on land) does not record SST and dew point temperature

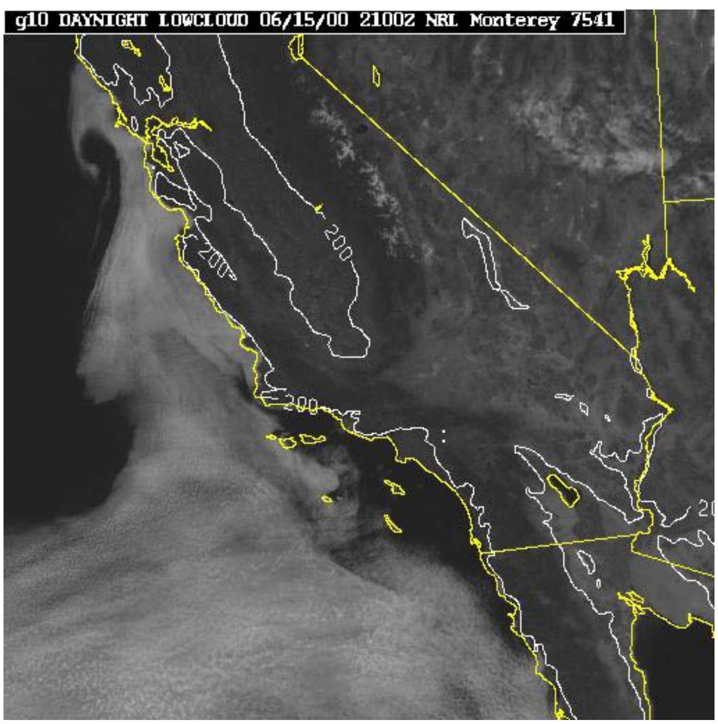

Figure 1. Satellite image valid 2100 UTC 15 June 2000.

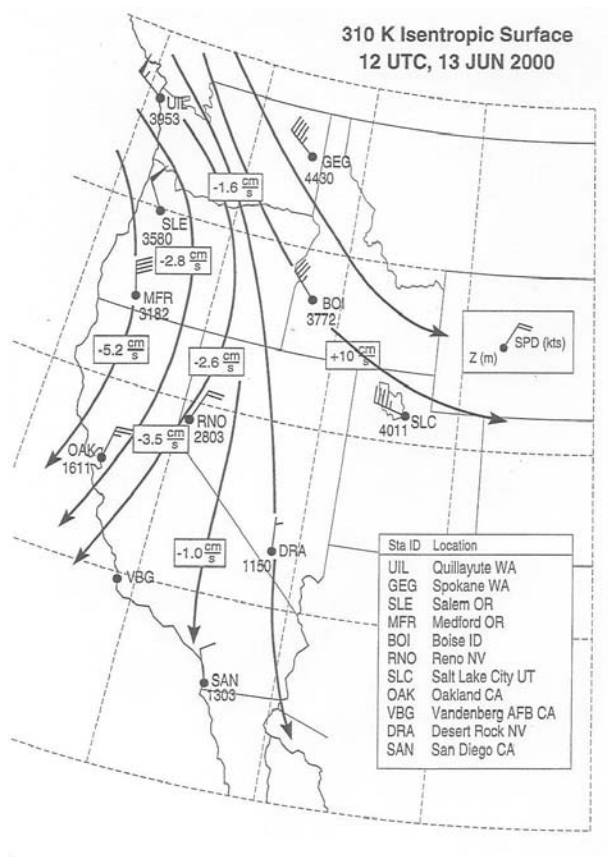

Figure 2. 310 K isentropic surface analysis valid 1200 UTC 13 June 2000.

and SST are missing on some of the buoy records]. The salient features from these time series are the following:

(1) A wind shift from northwesterly to southerly is indicated in the buoy and C-MAN records. This shift first appears in the south and moves northward;
(2) the SSTs decrease from south to north - 18/19 ^oC at Catalina Ridge to 9/10 ^oC at Bodega Bay;
(3)When foggy surface air is tracked in a Lagrangian frame (moving with the wind), the temperature is found to decrease;
(4) In the California Bight, the SST>T_a, but to the north at Bodega Bay, SST<T_a .

Based on these features, the cooling of the foggy air appears to have contributions from both the turbulent transfer at the sea surface and the radiation cooling at the top of the fog layer.

B. *Model Results*

At 1200 UTC (0500 LT) 15 June 2000, results from the Naval Research Laboratory Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS) indicate that flow is southerly along the coast from Pt. Conception to Monterey Bay. The shift from northwesterly to southerly at Monterey occurs at 1200 UTC (0500 LT) 15 June 2000 in close agreement with the buoy observations (see fig. 3). Southerly flow continues to propagate to the north, arriving at Bodega Bay at 1600 UTC (0900 LT). This is also in good agreement with observations. The speed of propagation of the wind shift from Monterey to Bodega Bay is ~12 m s^{-1}, which is fairly consistent with observations of the 10-11 June 1994 event (11 m s^{-1} ; [7]).

The tongue of fog has reached Pt. Piedras Blancas at 1200 UTC (0500 LT) and propagates to Monterey by 1700 UTC (1000 LT) and Bodega Bay by 0000 UTC (1700 LT). Shown in Fig. 4 is the region over which the cloud liquid water mixing ratio at 10 m elevation exceeds 0.01gm/Kg (the fog "footprint") at 0000 UTC (1700 LT 15) 16 June. The fog extends from Bodega Bay to the northern portion of the Southern California Bight and

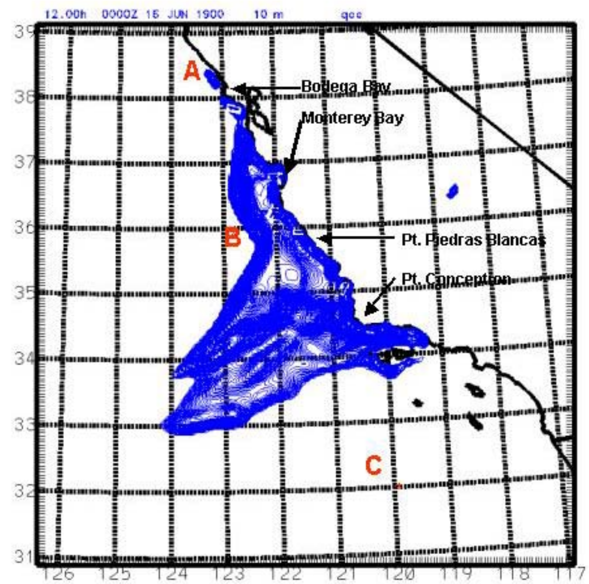

Figure 4. 12 h forecast valid 0000 UTC 16 August 2000 showing fog "footprint" (see text).

offshore to 33^{o}N, 124^{o}W. To the south of the shaded region, fog lifts away from the surface to form low clouds which extend to the southern boundary of the domain and from the coast to the western boundary of the domain.. Also shown in Fig. 4 are the locations of points A, B, and C. Examination of profiles of potential temperature, turbulent kinetic energy (tke), and cloud liquid water mixing ratio (Fig 5) indicates that, at point A, the boundary layer is quite stable with the potential temperature increasing from 286^{o}K to 296^o in the lowest 100 m. The tke is quite small. At point B near the center of the fog region, the fog extends to 200 m and has a peak water content of 1 gm/Kg. There is a shallow (100 m) mixed layer and the tke peaks near the base of the fog at 1 m^2s^{-2}. At point C in the low cloud regime, the cloud base is at 200 m and the layer is 250 m deep. The peak water content is .3 gm/Kg. There is a 400 m deep mixed layer and the tke peaks in the lower part of the cloud layer at 2.2 m^2s^{-2}.

C. *Sensitivity Studies*

Two important characteristics of the cloud field in this event are 1) the areal extent of fog as compared to the extent of low clouds

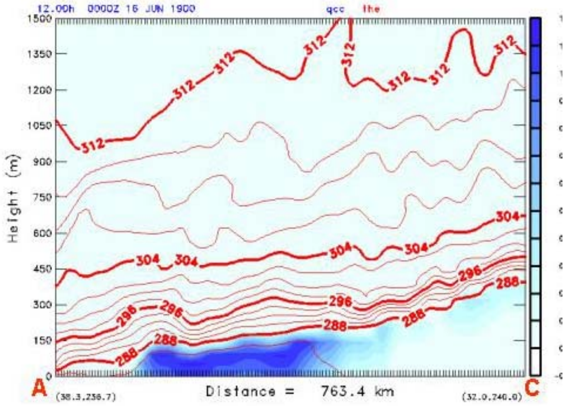

Figure 5. Cross section of potential temperature (K) and cloud water mixing ratio (gm/Kg; shaded) in the plane A-C.

and 2) the location of the northern end of the tongue. Given the relatively cold ocean surface temperature along the coast north of Point Conception and the somewhat warmer ocean surface temperature in the southern California Bight, it seems plausible that surface latent and sensible heat fluxes may play an important role in determining the extent of fog and low clouds. In an effort to understand the relative importance of these fluxes, sensitivity studies are performed. In each of several 12 h simulations, the initial conditions are identical to the control. In the first of the sensitivity studies, both latent and sensible surface heat fluxes are removed at all ocean grid points. In the second, latent heat flux is removed at all ocean grid points, and, in the third, sensible heat flux is removed.

The results of the simulation in which both fluxes are removed are remarkably similar to the control, at least in terms of the coarse structure, indicating that boundary layer moistening due to latent heat flux (tending to enhance cloudiness) and warming due to sensible heat flux (tending to reduce cloudiness) are nearly compensating one another.

The removal of the individual fluxes, however, has a dramatic impact on the distribution of the fog, both in terms of areal extent and the location of the northern edge. Somewhat paradoxically, the simulation in which latent heat flux is removed has both the smallest areal coverage and the greatest northern extent while the simulation in which sensible heat flux is removed has both the largest areal coverage and the smallest northern extent.

3. CONCLUSIONS

Investigation of the CTD event of 15 June 2000 has shed light of several aspects of cloud liquid water field associated with the CTD. The synoptic features leading to the "heat wave" which typically precedes CTD's are identified using isentropic analyses. Using the COAMPS model, the distribution of fog and low clouds is documented and the boundary layer structure within the tongue of low clouds and fog is investigated. Model results are shown to be in reasonable agreement with satellite imagery and buoy observations.

Analysis of the results of the sensitivity studies reveals some of the aspects of the roles of surface sensible and latent heat fluxes in this CTD event. Along most of the coast in the fog and low cloud regime, both surface sensible and latent heat flux are upward. Upward sensible heat flux warms the boundary layer and enhances entrainment of dry air, tending to reduce cloudiness. Upward latent heat flux tends to moisten the boundary layer and promotes cloudiness. North of San Francisco, the ocean surface temperature is particularly cold and latent and sensible heat fluxes are downward. Downward sensible heat flux results in cooling of the layer, promoting cloudiness while downward latent heat flux leads to drying, tending to reduce cloudiness. This is borne out by the results of the simulation is which the fluxes are removed individually.

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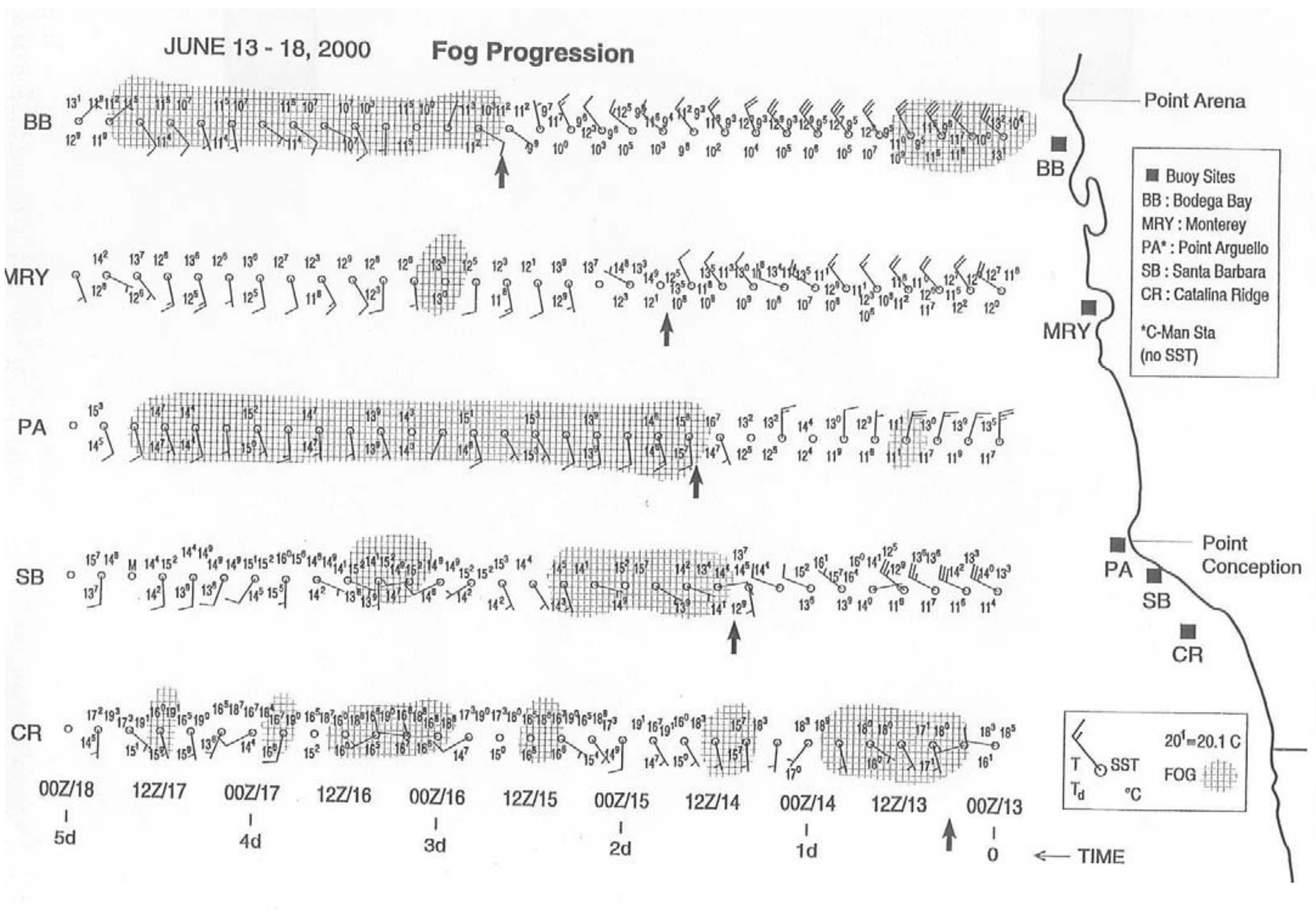

Figure 3. Time series of buoy observations.